Venturi Rx Nozzle's

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HITACHI KK   *EP -205-162-A
  12.06.85-JP-126109 *(17.12.86)* G21c-03/32 G21c-15/02
Resistance orifice in a nuclear fuel assembly - prevents flow instability without employing moving parts
  C86-144536   E(DE FR IT SE)
 	
A fuel assembly for a nuclear reactor has a bundle of fuel rods, upper and lower tie plates, and a resistance device located in the lower tie plate. The resistance device comprises a set of round bars which form coolant passageways.
  Throat portions are formed between the bars so that the cross sectional area increases continuously towards the upper and lower stream sides.
 	
ADVANTAGE
  Prevents flow instability, under the low flow state of a coolant, without employing moving parts.
 	
PREFERRED EMBODIMENT
  The fuel assembly (45) arranged in the core shroud is supported by a lower tie plate (38) which is positioned in the outlet openings (24) of the coolant passageways (22) of the fuel support fixtures (3).
	K(5-B4B)
	
	  The resistance device (25) is mounted on the lower tie plate (38) and is constructed of 13 round bars (27). The bars are attached to a ring (26) and are equally spaced and parallel to one another.
	  A gap (28) formed between adjacent bars (27) serves as the cooling water passage. It has a cross sectional area which constantly increases, from the narrowest portion of the throat (8a), towards the upper and lower stream sides. (51pp1761RKMHDwgNo14b,17/24).
	(E)ISR: No Search Report.
	
	                                                    EP-205162-A*

47 26 45 38 58 57 8A 3 27 24 25 28 21 33 27 22 23 28 29 39 25

EP-205

(12) # EUROPEAN PATENT APPLICATION

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(54) Reactor fuel assembly and nuclear reactor.

(57) Fuel support fixtures having first cooling water passageways (22) therein are mounted on a core support member which is disposed in a reactor pressure vessel. Each of fuel assemblies is supported in such a way that its lower tie plate having a second cooling water passageway (57) therein is inserted in the first cooling water passageway (22) of the fuel support fixture. A resistance device (25) which has a plurality of round bars being resistance members (27) is disposed in either the first or second cooling water passageway. A coolant passage (28) formed between the adjacent round bars has a throat portion (8A), and expands continuously from the throat portion (8A), toward an upper stream side and a lower stream side respectively. The opposing side walls of the coolant passage (28) are the respective surfaces of the adjacent round bars.

FIG. 17

EP 0 205 162 A2

FIG. 1

FIG. 2

FIG. 3

FIG. 4A

FLOW RATE

X0

X2

0   TIME

FIG. 4B

FLOW RATE

X0

X2

0   TIME

FIG. 6A

VI

5

FL

8

6

7

VI

FIG. 6B

5

7

8A

W1

W2

8

6
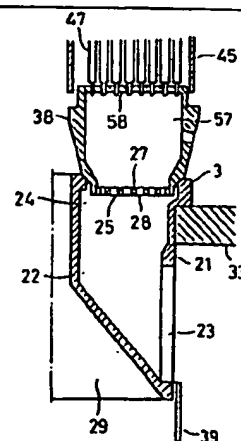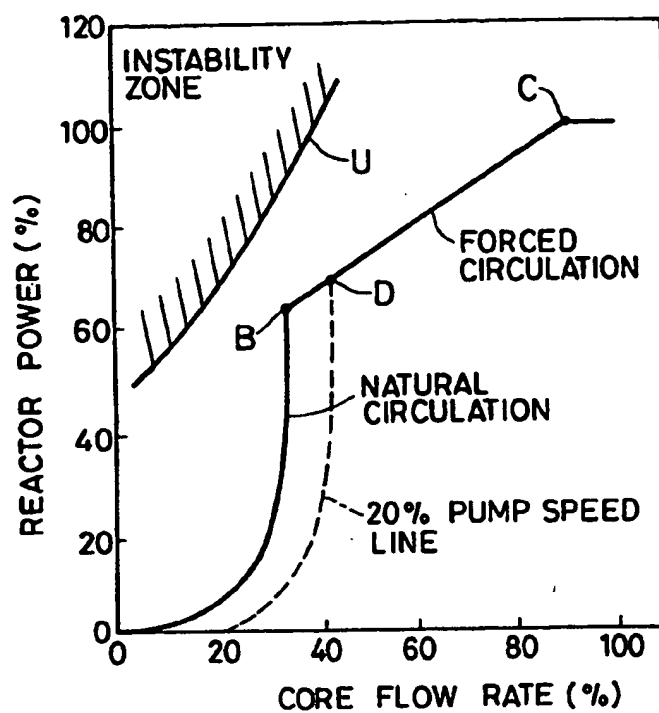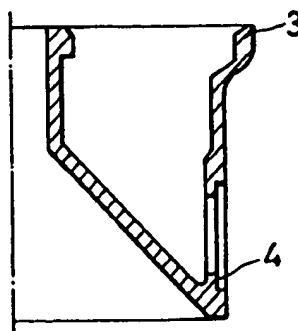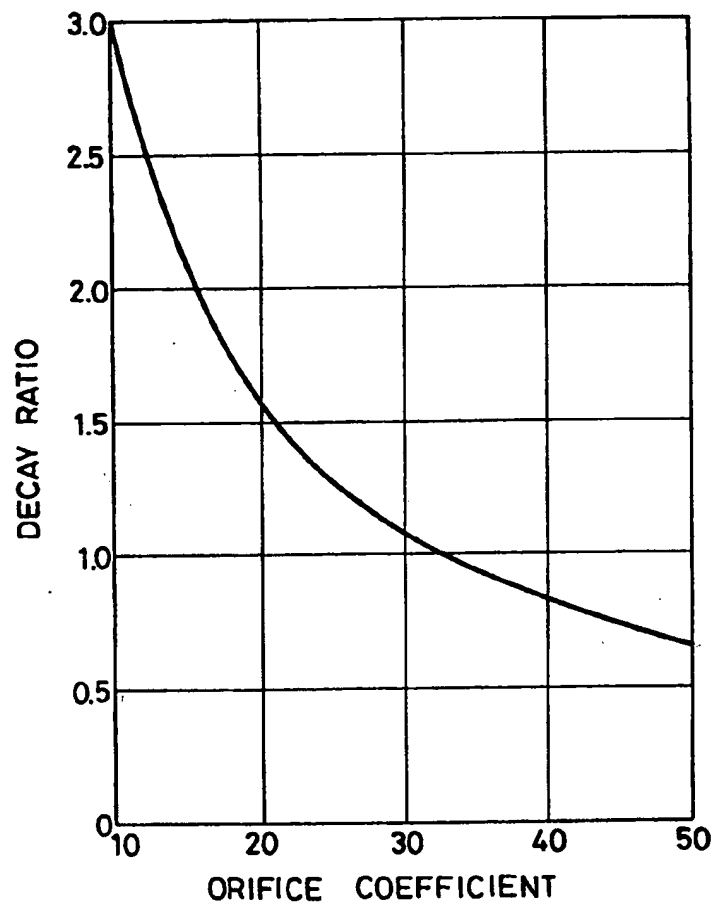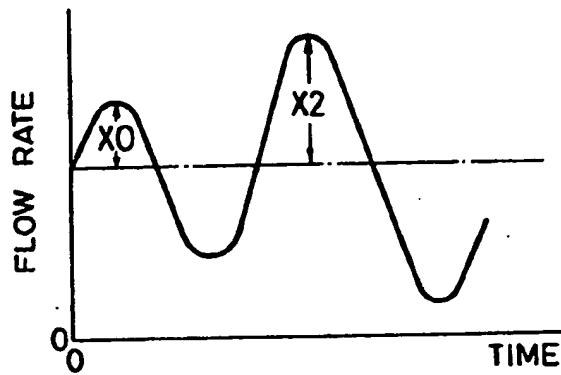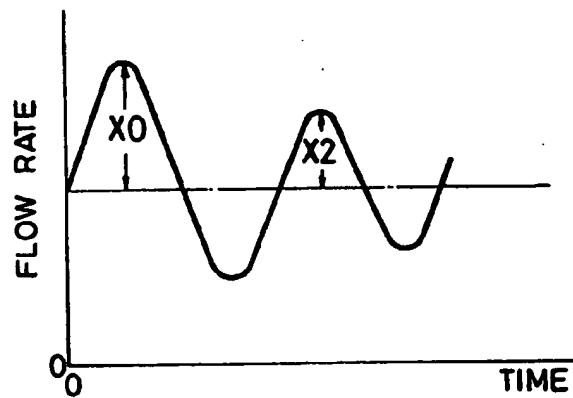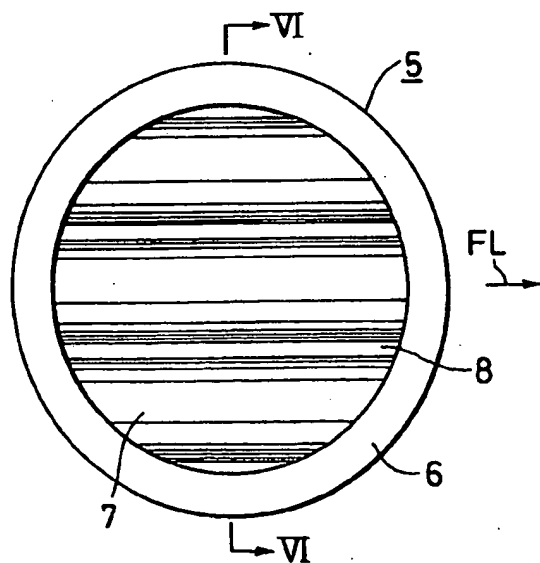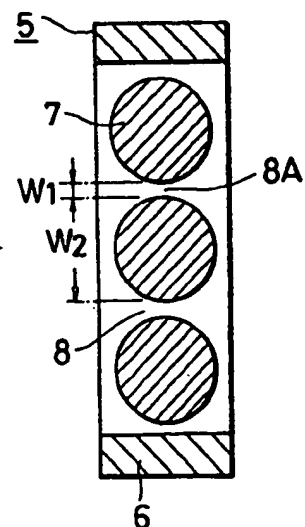
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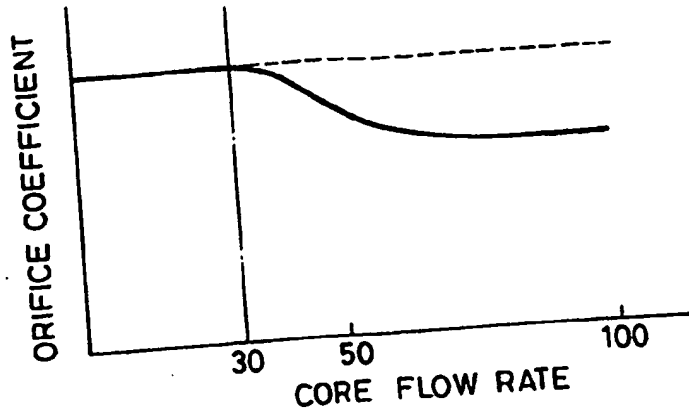
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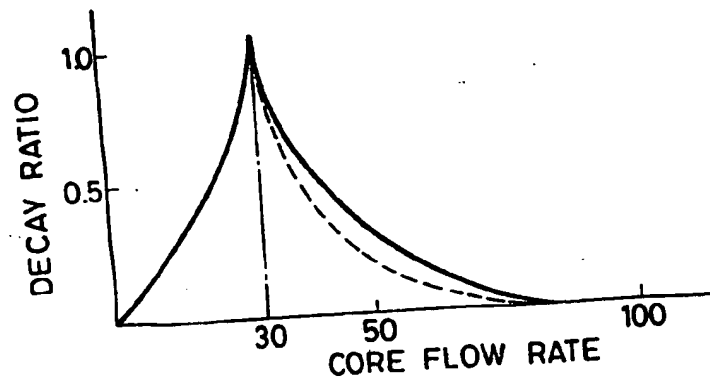
FIG. 5C

FIG. 7

FIG. 8
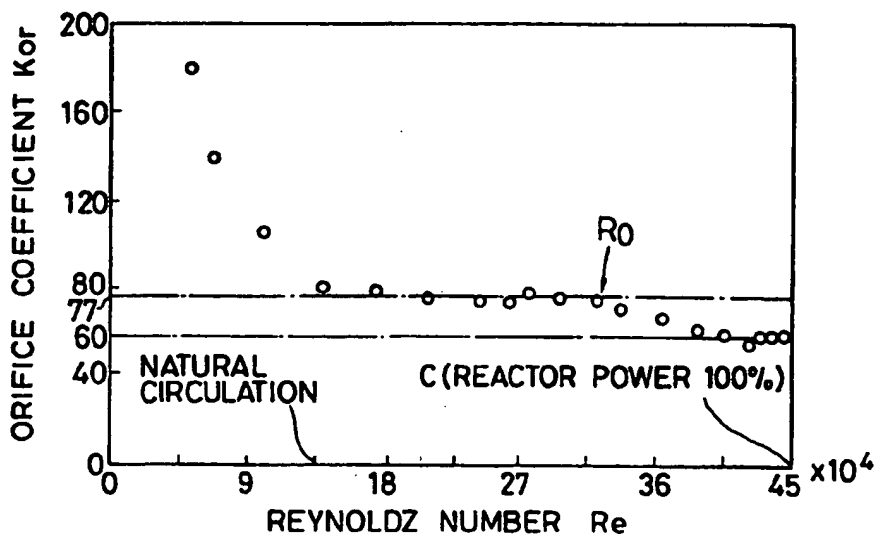
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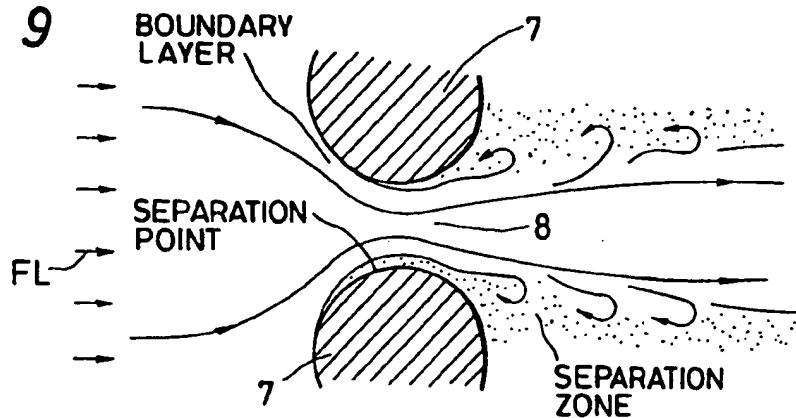
FIG. 10
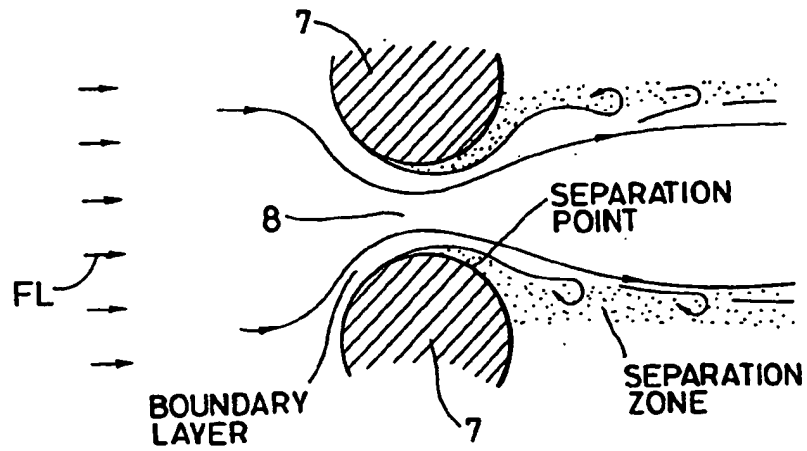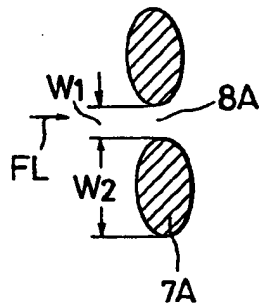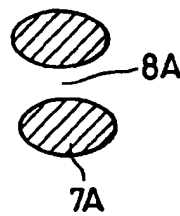
FIG. 11A　FIG. 11B　FIG. 11C
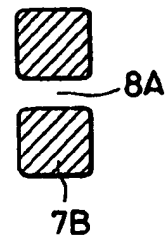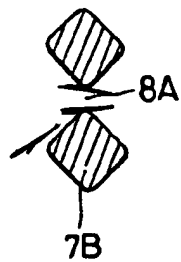
FIG. 11D　FIG. 11E　FIG. 11F

FIG. 12

FIG. 13

46

55

56

47

45

54

53

SPRING PLATES

58

27

57

38 LWR TIE PLATE

28   25 — ORIFICE

50

52

47

48

51

49

FIG. 14A

X₁

25

26

27

28

X₁

FIG. 14B

26

8A

27

28

25

FIG. 17

47

45

38

58

57

27

3

24

25

28

24

21

33

H₂O PASSAGEWAY 22
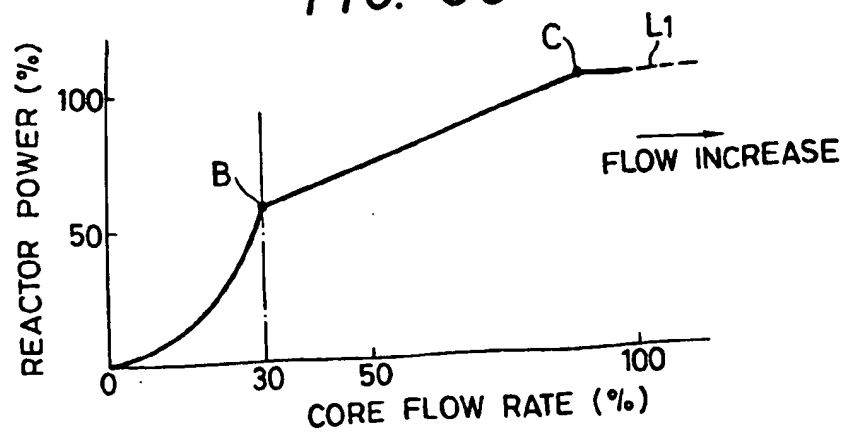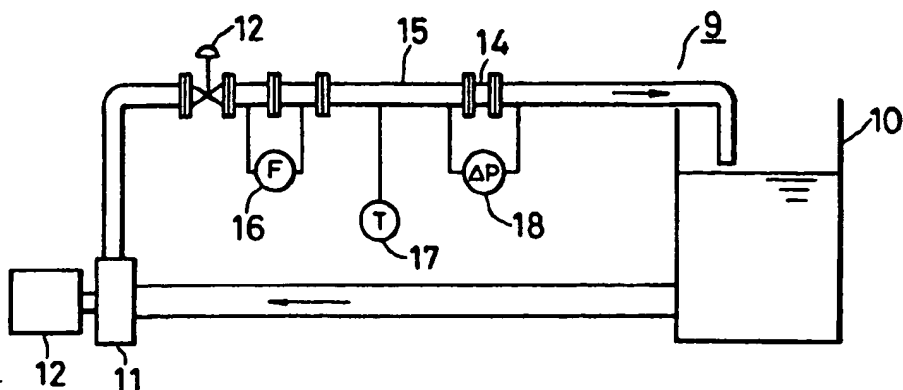
23

21

23

29

39

FIG. 16

24

29

24

24

24

21

23

3
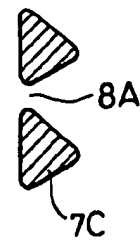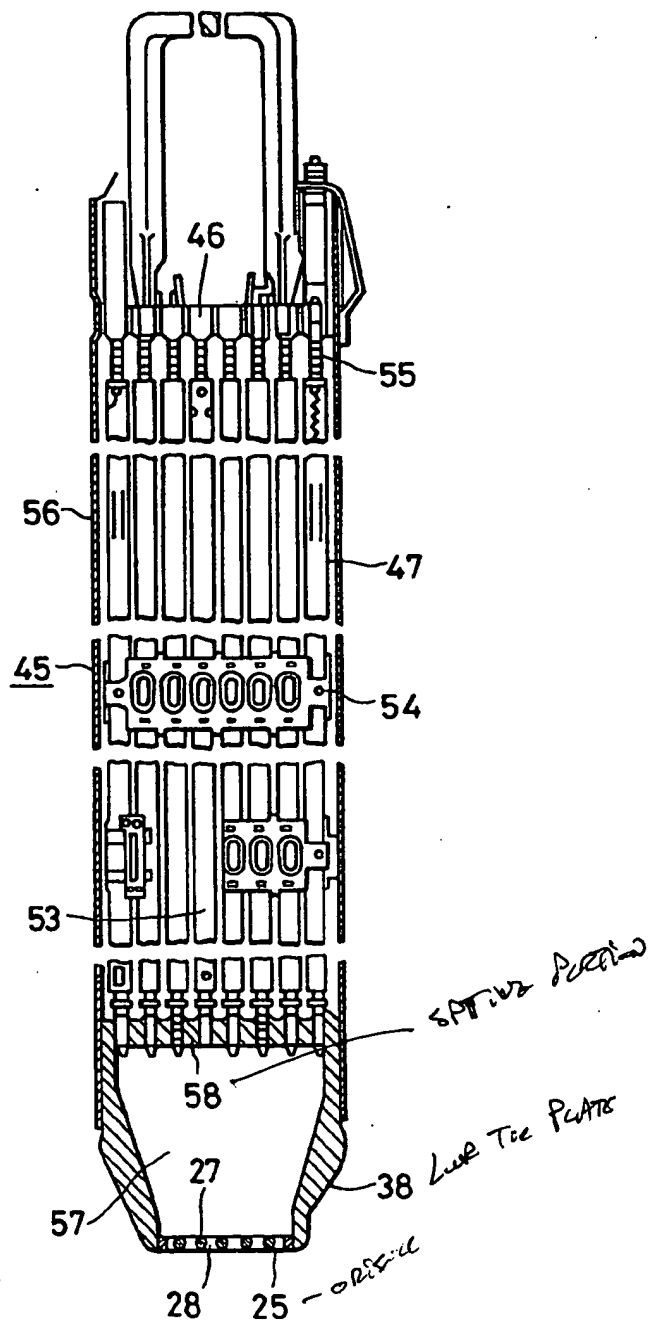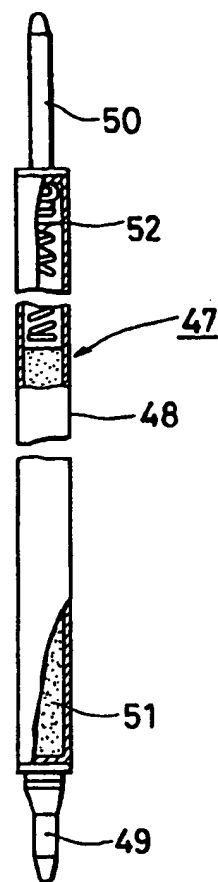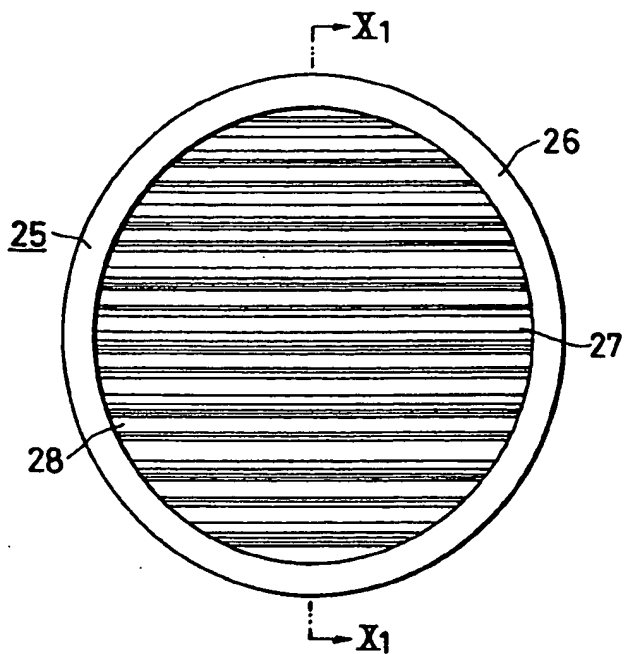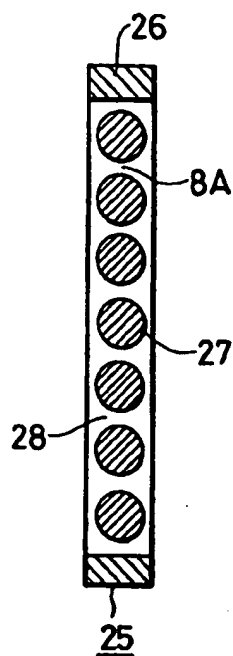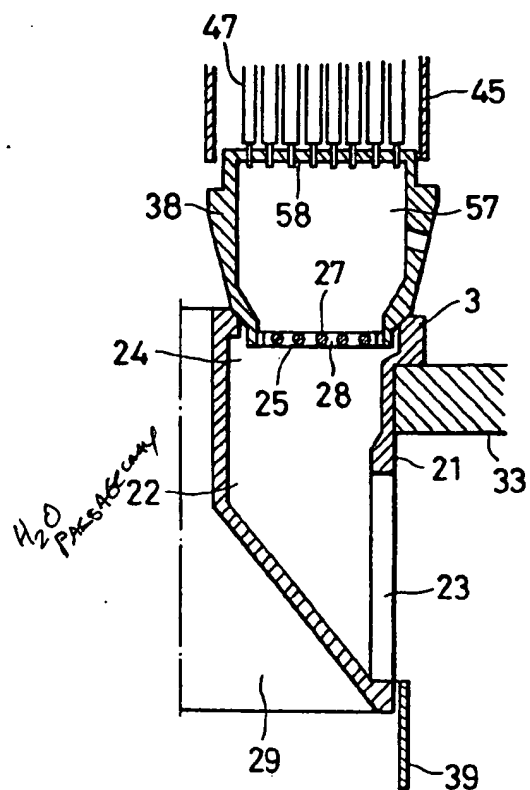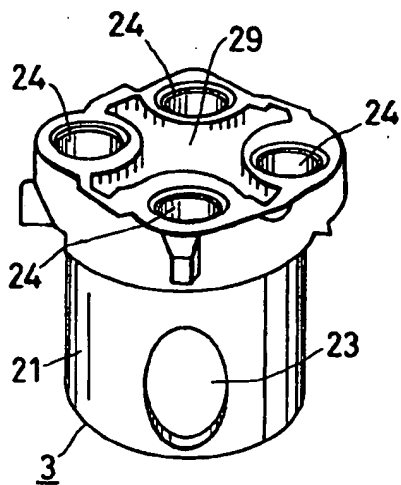
FIG. 15
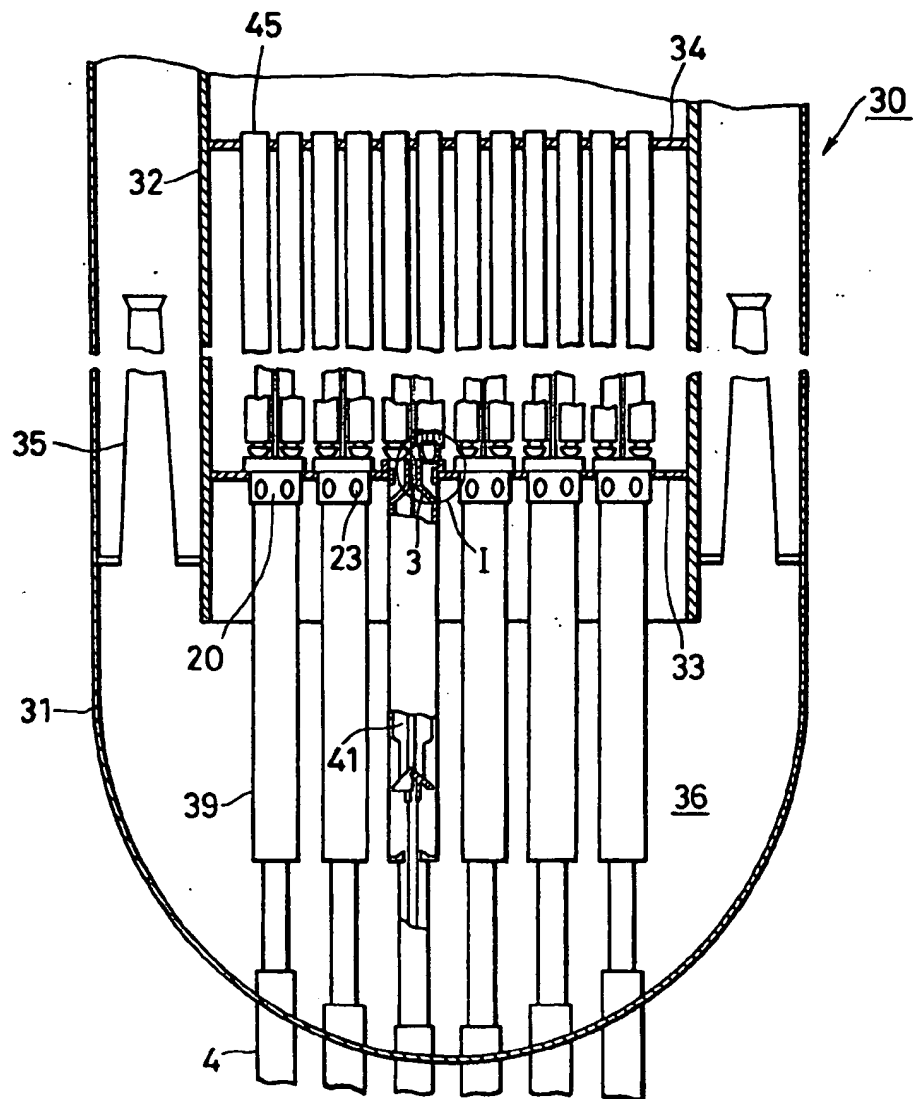
FIG. 18
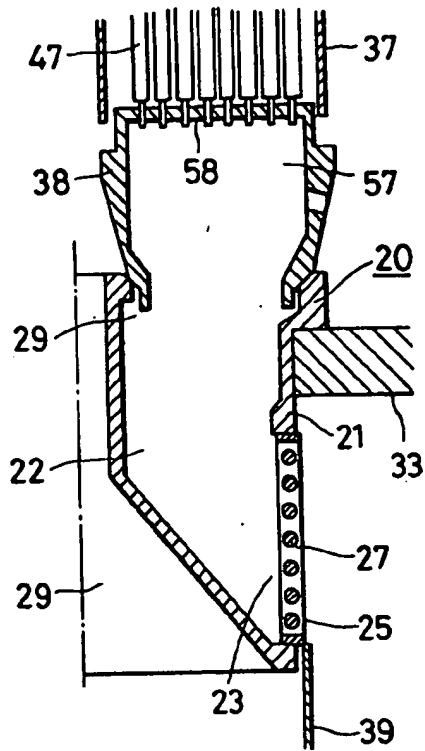
FIG. 19

FIG. 20A

FIG. 20B

FIG. 21

27B

F

FIG. 22A

X₃

26

28

FL

27C

25C

27C

X₃

FIG. 22B

26

27C

8A

25C

FIG. 23A

25D

X4

27

28

26

X4

FIG. 23B

26

27

FL

8A

28

25D

FIG. 24A

25E

X5

26

27

28

X5

FIG. 24B

26

27

8A

FL

28

25E
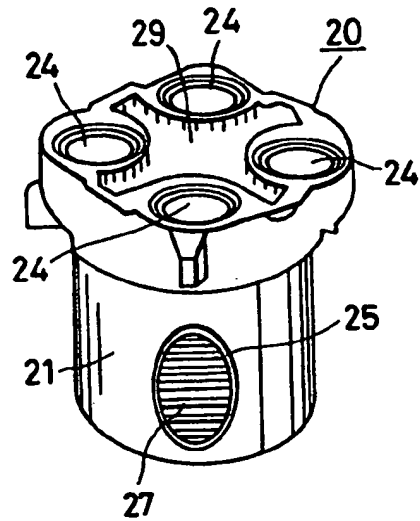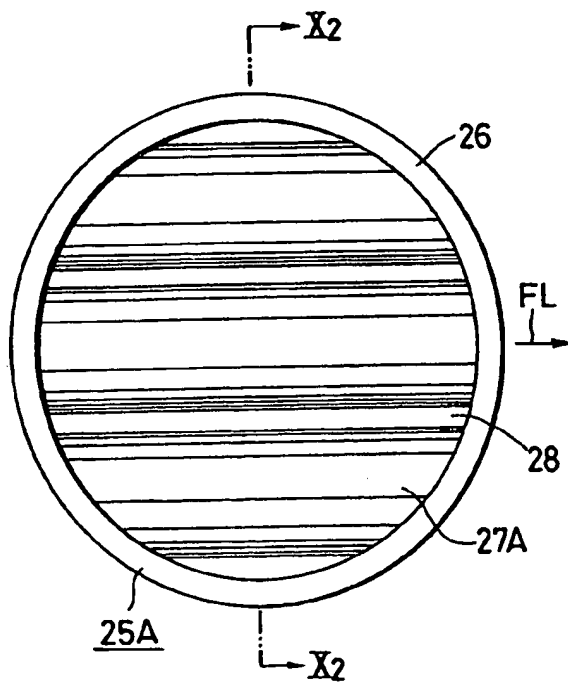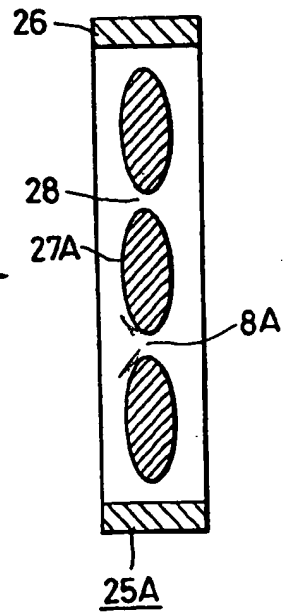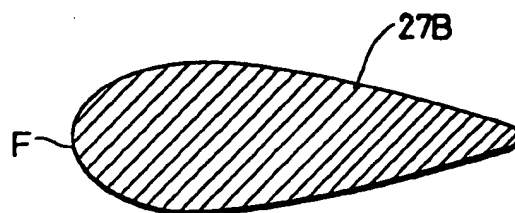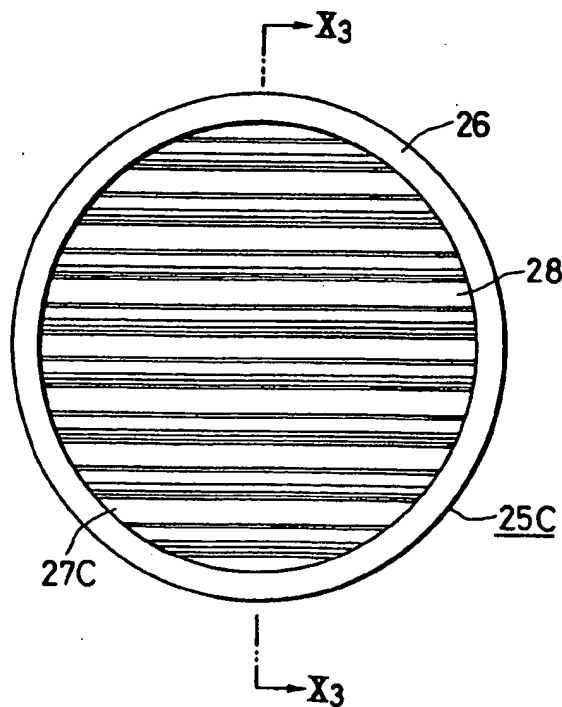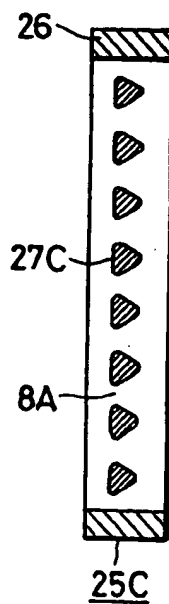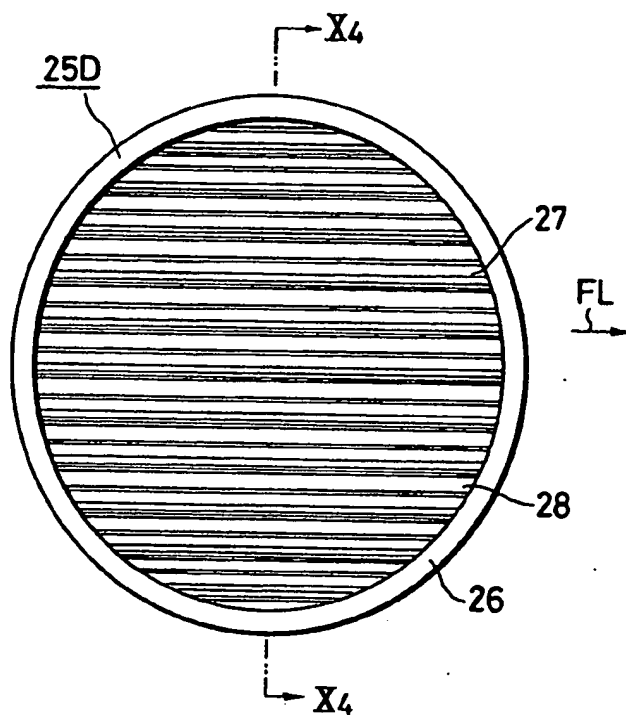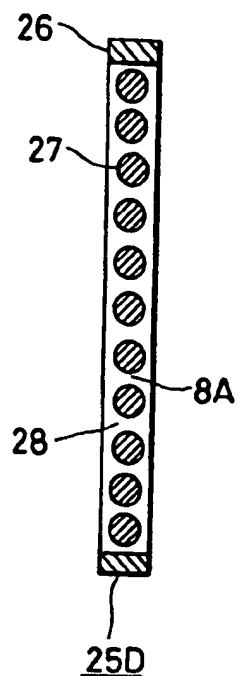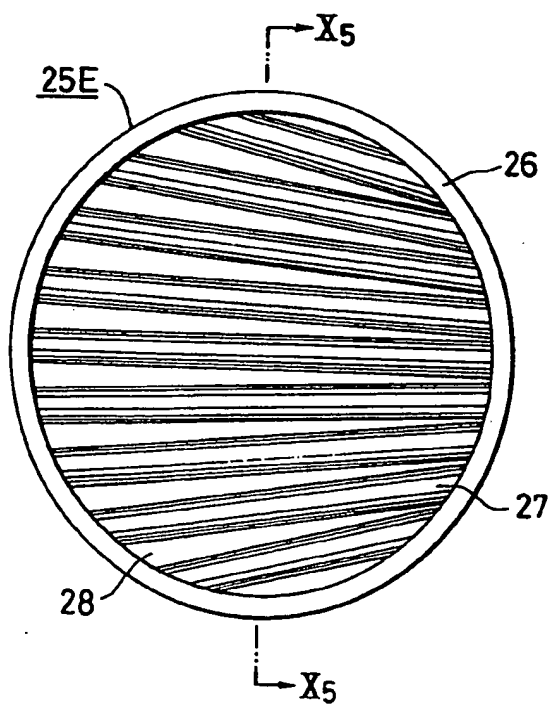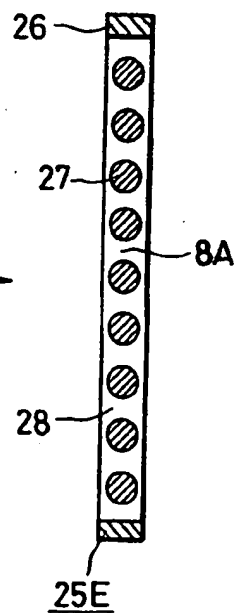
Title of the Invention:

    REACTOR FUEL ASSEMBLY AND NUCLEAR REACTOR

Background of the Invention:

    The present invention relates to a reactor fuel
assembly and a nuclear reactor, and more particularly
to a fuel assembly and a reactor structure well-suited
for application to a boiling water reactor.

    A boiling water reactor generates steam in a core
within a reactor pressure vessel, and supplies the steam
to a turbine.

    Since, in the boiling water reactor, the voids
of the steam rise inside the core, enhancement in the
nuclear thermal hydraulic stability has been studied.
The official gazette of Japanese Patent Application
Laid-open No. 57-52897, Fig. 5, shows a construction
which enhances the nuclear thermal hydraulic stability
in the boiling water reactor. The construction will
be explained below. The boiling water reactor is such
that a lower core support plate disposed in the reactor
pressure vessel is provided with a fuel support fixture,
and that a fuel assembly is supported by the fuel support
fixture with its lower end inserted in the upper opening
of a cooling water channel provided in the fuel support
fixture. An orifice having one round opening is mounted
on the inlet part of the cooling water channel in the

fuel support fixture. The amount of voids of the core

where the fuel assembly is arranged is measured, and

according to the measured amount of voids, an orifice

shield plate is controlled to regulate the open area

of the orifice. When a nuclear thermal hydraulic instability

has occurred, the amount of voids in the fuel assembly

increases. Therefore, in a case where the amount of

voids has exceeded a predetermined quantity, the orifice

shield plate is lowered, whereby the open area of the

orifice is increased to temporarily raise the rate of

flow and to prevent the increase of the amount of voids.

Thus, the nuclear thermal hydraulic instability is eliminated.

Summary of the Invention:

An object of the present invention is to prevent

a flow instability under the low flow rate state of a

coolant without employing a movable portion.

The present invention is characterized in that
a resistance device is disposed in a coolant channel,
that the resistance device has a plurality of coolant
passages formed with throat portions, that the cross-
sectional area of each of the coolant passages increases
continuously from the throat portion toward an upper
stream side and a lower stream side respectively, and
that each of the opposing side walls of the coolant

passage is made of a continuous surface which has no
angled part from the upper stream side of the throat
portion to the lower stream side thereof.
Brief Description of the Drawings:
    Fig. 1 is a characteristic diagram showing the
relationship between the core flow rate and the reactor
power;
    Fig. 2 is a partial vertical sectional view of
a fuel support fixture in a prior art;
    Fig. 3 is a graph showing the relationship between
the orifice coefficient and the damping ratio;
    Fig. 4A is an explanatory diagram showing the state
of a damping ratio during an unstable flow, while Fig. 4B
is an explanatory diagram showing the state of a damping
ratio during a stable flow;
    Fig. 5A is a graph showing the variation of the
orifice coefficient versus the core flow rate, Fig. 5B

is a graph showing the variation of the damping ratio

versus the core flow rate, and Fig. 5C is a graph showing

the variation of the reactor power versus the core flow

rate;

Fig. 6A is a front view of the test piece of an

orifice for use in the present invention, while Fig. 6B

is a sectional view taken along plane VI - VI in Fig. 6A;

Fig. 7 is a structural view of an experimental

device for conducting the flow experiment of the orifice

in Fig. 6A;

Fig. 8 is a graph showing the variation of the

orifice coefficient based on the result of the flow

experiment of the orifice in Fig. 6A;

Fig. 9 is an explanatory diagram showing a flow

state for a region $R_e < R_{ec}$ (R_e: Reynolds number, R_{ec}:

critical Reynolds number) in an orifice interspace in

Fig. 6B, while Fig. 10 is an explanatory diagram showing

a flow state for a region $R_e > R_{ec}$ in the orifice interspace

in Fig. 6B;

Figs. 11A - 11F are sectional views showing different

embodiments of resistors which are disposed in orifices;

Fig. 12 is a vertical sectional view of a fuel

assembly which is an embodiment of the present invention;

Fig. 13 is a structural view, partly broken away,

of a fuel rod in Fig. 12;

Fig. 14A is a front view of an orifice in Fig. 12,
while Fig. 14B is a sectional view taken along plane
$X_1 - X_1$ in Fig. 14A;

Fig. 15 is a partial vertical sectional view of
a boiling water reactor which is an embodiment of the
present invention;

Fig. 16 is a perspective view of a fuel support
fixture in Fig. 15;

Fig. 17 is an expanded view of part I in Fig. 15;

Fig. 18 is a vertical sectional view of a part corresponding
to the part I in Fig. 15, showing a boiling water reactor
which is another embodiment of the present invention;

Fig. 19 is a perspective view of a fuel support
fixture in Fig. 18;

Fig. 20A is a front view of another embodiment of
an orifice, while Fig. 20B is a sectional view taken
along plane $X_2 - X_2$ in Fig. 20A;

Fig. 21 is a vertical sectional view of another
embodiment of a resistor; and

Figs. 22A, 23A and 24A are front views each showing
another embodiment of an orifice, while Figs. 22B, 23B
and 24B are sectional views respectively taken along
plane $X_3 - X_3$ in Fig. 22A, plane $X_4 - X_4$ in Fig. 23A
and plane $X_5 - X_5$ in Fig. 24A.

Description of the Preferred Embodiments:

The present invention has been made on the basis
of the result of study on the unstable phenomenon of
a boiling water reactor in a prior art. The contents
of the study will be explained below.

The unstable phenomenon of the boiling water reactor
arises in a region above a curve U in Fig. 1. That
is, the unstable phenomenon arises in a region in which
the flow rate of cooling water passing through a core
(hereinbelow, called "core flow rate") is low to cause
a high reactor power. In Fig. 1, a curve (in a solid
line) connecting a point A and a point B indicates the
variation of the reactor power in the case of manipulating
a control rod in the state in which the core flow rate
is given by natural circulation. A straight line connecting
the point B and a point C indicates the variation of
the reactor power in the case of changing the core flow
rate while the degree of insertion of the control rod
into the core is held constant. In this case, the
cooling water is forcibly supplied to the core by a
recirculation pump. A characteristic depicted by a
broken line in Fig. 1 indicates a reactor power variation
in the case where a core flow rate equal to 20 % of
a rated value is established by the recirculation pump.
The point C corresponding to the rated state (100 %
reactor power) is sufficiently distant from the unstable

region, so that a stability margin is ensured therefor.

Since, however, the natural circulation state of the

curve AB (the state in which the cooling water is circulated

by the buoyancy of voids produced in the core) is close

to the unstable region, it has a small stability margin.

In the prior-art boiling water reactor, to the

end of increasing the stability margin in the natural

circulation state, the cooling water inlet of a fuel

support fixture 3 supporting the lower end of a fuel

assembly is provided with an orifice 4 as shown in Fig. 2.

The effect of the orifice 4 in the natural circulation

state is illustrated in Fig. 3. The axis of abscissas

in Fig. 3 represents the orifice coefficient which indicates

the flow resistance of the orifice 4, while the axis

of ordinates represents the damping ratio which is the

indicator of the stability. The damping ratio is the

ratio between the amplitudes of adjacent sinusoidal

waves (X2/X0) as shown in Fig. 4A or Fig. 4B, and expresses

the fluctuation damping factor of the flow rate or the

like. The state of Fig. 4A under which an inequality

(X2/X0 > 1) is satisfied is an unstable flow state.

On the other hand, the state of Fig. 4B under which

an inequality (X2/X0 < 1) is satisfied is a stable flow

state. When the effect of the orifice 4 is studied

in terms of the damping ratio, the stability is enhanced

with increase in the orifice coefficient (with increase

in the flow resistance by the orifice 4) as shown in

Fig. 3. The safety becomes problematic in the natural

circulation state in which the damping ratio approximates

1.0 as indicated by a broken line in Fig. 5B, and especially

near the point B in Fig. 1. As regards the orifice

4 of the fuel support fixture 3 in the prior art, even

when the reactor power varies with the increase of the

core flow rate as indicated by a broken line in Fig. 5C,

the orifice coefficient remains constant as indicated

by a broken line in Fig. 5A. With the orifice 4 having

such an orifice coefficient, the damping ratio varies

as indicated by the aforementioned broken line in Fig. 5B.

As the orifice 4 of the fuel support fixture 3 in the

prior art, there has been employed one having an orifice

coefficient set on the premise of avoiding the unstable

state in the natural circulation state. This orifice

coefficient is always constant as indicated by the broken

line in Fig. 5A.

With note taken of the fact that the prevention

of the unstable state for small core flow rates (during

the natural circulation) and the increase of the range

of the control of the reactor power by the core flow

rate can be achieved by furnishing a fuel assembly or

a fuel support fixture with a mechanism which does not

employ any movable part and according to which a pressure

loss increases during the natural circulation of cooling

water with the small core flow rates whereas the pressure

loss decreases when the core flow rate is large, the

inventors made various studies and experiments in order

to find out the practicable structure of the aforementioned

mechanism. The studies and experiments have revealed

that an orifice 5 having the shape of an opening as

shown in Figs. 6A and 6B meets the conditions mentioned

above.

The orifice 5 is such that three round bars 7 are

arrayed in parallel within a ring 6 with gaps or interspaces

8 defined between the adjacent round bars and have both

their ends attached to the ring 6, whereupon a coolant

flows through the gaps 8 in the direction of arrow FL.

The sectional shape of the gap 8, namely, a coolant passage

in the direction of the arrow FL is such that the cross-

sectional area decreases gradually in the flow direction

on the upper stream side of a throat portion 8A being

the narrowest and increases gradually in the flow direction

on the lower stream side of the throat portion 8A, and

that both sideward walls forming the gap 8 (the surfaces

of the round bars 7) are continuous planes having no

angled part. The shape of the gap 8 in the axial direction

of the round bar 7, particularly the shape of the throat

portion 8A, is an elongate shape which is determined
by the axial shape of the side surfaces of the opposing
pair of round bars 7. The flow characteristics of the
orifice 5 were obtained by the use of an experimental
device 9 shown in Fig. 7. The schematic construction
of the experimental device 9 will be described. The
experimental device 9 is so constructed that a tank
10 filled with water, a pump 11, a flow rate regulator
valve 13 and a test piece 14 are connected by piping
15. One end of the piping 15 is open over the tank
10. The pump 11 is driven by a motor 12. The orifice
5 shown in Fig. 6A is set in the test piece 14. The
flow rate and temperature of water which is fed into
the test piece 14 are respectively measured by a flow
meter 16 and a thermometer 17. The differential pressure
between the upper stream side and lower stream side
of the test piece 14 is measured by a differential pressure
gauge 18.

In the flow test of the orifice 5, the pump 11
is driven to supply the water in the tank 10 to the
orifice 5 in the test piece 14 through the piping 15.
The flow rate of the water to be supplied is controlled
by the flow rate regulator valve 13.

When the measurement data items of the flow rate,
differential pressure and temperature obtained with

the experiment were rearranged, characteristics in Fig. 8
were found. The axis of abscissas in Fig. 8 represents
the Reynolds number R_e, while the axis of ordinates
represents the orifice coefficient K_{or}. The orifice
coefficient K_{or} of the orifice 5 becomes about 77 near
$R_e = 13 \times 10^4$ corresponding to the natural circulation
state (the point B in Fig. 1) of the boiling water reactor,
and becomes about 60 for $R_e = 45 \times 10^4$ corresponding

to the reactor power 100 % (the point C in Fig. 1) of
the boiling water reactor. The orifice coefficient
K_{or} at the point C in Fig. 1 is about 22 % lower than
that at the point B in Fig. 1. Consequently, the pressure
loss at the point C becomes about 22 % lower than that
at the point B. The orifice coefficient K_{or} of the orifice
5 is substantially constant at about 77 in an R_e range
of $13 \times 10^4 - 30 \times 10^4$, and decreases gently when R_e
exceeds 30×10^4. The point of $R_e = 30 \times 10^4$ corresponds
to a core flow rate of about 60 % in Fig. 1.

In this manner, the orifice 5 furnished with the
plurality of round bars has no movable part, and it
has the function according to which the orifice coefficient
is reduced by the increase of the flow rate (that is,
the pressure loss is lowered by the increase of the
flow rate).

The reasons why the characteristics illustrated

in Fig. 8 appear will be described with reference to
Figs. 9 and 10. Fig. 9 shows the flow state of water
between the adjacent round bars 7 of the orifice 5 for
$R_e = 13 \times 10^4$ under the natural circulation state in
Fig. 8. The water is flowing in the direction of arrows
FL. In this case, a boundary layer which is formed
along the surface of each round bar 7 is a laminar boundary
layer. A burble point is a position at which the boundary
layer separates away from the surface of the round bar
7, and it is formed on an upper stream side with respect
to a perpendicular which passes through the axes of
the round bars 7. A burble region is formed on the
lower stream side of the burble point. A pressure in
the burble region formed downstream of the round bar
7 becomes lower than a pressure in a region where the
boundary layer does not separate on the upper stream
side of the round bar. Accordingly, a pressure difference
arises between the upper stream side and lower stream
side of the gap 8 which is formed between the adjacent
round bars 7, and a pressure loss arises therebetween.
Fig. 10 shows the flow state of water between the adjacent
round bars 7 of the orifice 5 for $R_e = 45 \times 10^4$ at the
point C in Fig. 8. In this case, a boundary layer which
is formed along the surface of each round bar 7 is a
turbulent boundary layer. A burble point is formed

on a lower stream side with respect to the perpendicular

which passes through the axes of the round bars 7. A

burble region which is formed downstream of the burble

point becomes smaller than in the case of Fig. 9. Accordingly,

the lower pressure region (the burble region) which

is formed behind the round bar 7 in the flow direction

lessens as compared with that in the case of Fig. 9,

and the pressure difference between the upper stream

side and lower stream side of the gap 8 becomes smaller.

The pressure loss between the upper stream side and

lower stream side of the gap 8 in Fig. 10 decreases

as compared with that in Fig. 9.

The flow within the boundary layer formed along

the surface of the round bar 7 is changed from the laminar

flow to the turbulent flow by increase in the velocity

of flow in the gap 8, namely, increase in the Reynolds

number R_e in the gap 8. The change of the boundary

layer formed along the surface of the round bar 7, from

the laminar boundary layer to the turbulent boundary

layer occurs as to Fig. 8, at the point at which the

orifice coefficient K_{or} begins to shift from 77, namely,

at the point of $R_e \fallingdotseq 33 \times 10^4$. This Reynolds number

of 33×10^4 is termed 'critical Reynolds number.' In

a region of $R_e < R_{ec}$, the boundary layer of the round

bar 7 is the laminar boundary layer, and the pressure

loss between the upper stream side and lower stream
side of the gap 8 becomes great, whereas in a region
of $R_e > R_{ec}$, the boundary layer is the turbulent boundary
layer, and the pressure loss between the upper stream
side and lower stream side of the gap 8 becomes small.

As a trend, the orifice coefficient of the orifice
5 decreases with the increase of the core flow rate
as indicated by a solid line in Fig. 5A (the orifice
coefficient is assumed to lower from the natural circulation
state at the point B). As shown in Fig. 5B, such decrease
in the orifice coefficient increases the damping ratio
of the orifice 5 in comparison with that of the orifice
4 in the prior art. However, the proportion of the
increase is small, and the damping ratio of the orifice
5 does not exceed 1.0.

Instead of the round bars 7 of the orifice 5, bars
7A - 7C having sectional shapes as shown in Figs. 11A
- 11F may well be combined as illustrated and attached
to rings 6. These orifices were subjected to flow experiments
similar to the experiment of the orifice 5. It has
consequently been revealed that, also with these orifices,
boundary layers formed along the surfaces of the bars
7A - 7C become laminar boundary layers for $R_e < R_{ec}$
and turbulent boundary layers for $R_e > R_{ec}$ likewise
to the case of the orifice 5. The critical Reynolds

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numbers R_{ec} of the orifices corresponding to Figs. 11A - 11F differ from one another. For the combinations of these bars, water was caused to flow in the direction of arrow FL. In Fig. 11A, the bars 7A having an elliptic section are so arranged that the major axis of each ellipse extends perpendicularly to the direction of the arrow FL. In Fig. 11B, the bars 7A are so arranged that the major axis of each ellipse extends in the direction of the arrow FL. In Fig. 11C, the bars 7B having a section of regular square are so arranged that one side of each regular square extends in the direction of the arrow FL. In Fig. 11D, the bars 7B are so arranged that one side of each regular square inclines by 45.° to the direction of the arrow FL. In Fig. 11E, the bars 7C having a section of regular triangle are so arranged that one corner part of each section faces an upper stream side. In Fig. 11F, the bars 7C are so arranged that one corner part of each section faces a lower stream side. In the bars 7B and 7C, each corner part of the section is not angled but is a smooth curved surface having any desired curvature.

The side walls of coolant passages defined between the bars or resistors shown in Fig. 6A and Figs. 11A - 11F (the side surfaces of the resistors) are formed of continuous smooth surfaces having no angled part

in the flow direction of the fluid in order that the

burble point may move from the upper stream side to

the lower stream side of the throat portion 8A as illustrated

in Figs. 9 and 10. If the side wall of the coolant

passage is formed with an angle part in the flow direction

of the fluid, a burble point will appear in the angled

part. Moreover, even if the velocity of flow increases,

the burble point will fail to move downstream of the

angled part. For this reason, it is impossible to attain

the characteristics shown in Fig. 8, namely, the phenomenon

that the pressure loss lowers in the region of $R_e > R_{ec}$.

The coolant flow rate which affords the critical

Reynolds number can be regulated by changing the sectional

shape and dimensions of the resistors (the bars shown

in Fig. 6 and Figs. 11A - 11F), while the pressure loss

can be regulated by the area of the passage which is

fined by the resistors. The width W_1 of the throat

portion 8A defined between the resistors is smaller

than the width W_2 of the resistor in the direction perpendicular

to the flow direction FL of the coolant.

According to such studied results, the inventors

have reached the conclusion that the coolant passage

(having a throat portion) of a resistance device (for

example, the orifice 5 stated before) may be constructed

so as to increase its cross-sectional area continuously

from the throat portion toward an upper stream side

and a lower stream side, while each of the side walls

of the coolant passage may be constructed of a smooth

continuous surface having no angled part so as to permit

a burble point to move between the upper stream side

and lower stream side of the throat portion, and that

the resistance device may be disposed in a fuel assembly

or a fuel support fixture. Embodiments of the present

invention satisfying such conditions will be stated below.

One preferred embodiment of the present invention

applied to a boiling water reactor will now be described.

The embodiment of a fuel assembly for the boiling

water reactor is shown in Fig. 12. The fuel assembly

45 of this embodiment is constructed of a channel box

56, a lower tie plate 38, an upper tie plate 46, spacers

54, fuel rods 47 and an orifice 25. The upper and lower

end parts of the fuel rod 47 are respectively held by

the lower tie plate 38 and the upper tie plate 46. Also

each water rod 53 has both its end parts held by the

lower tie plate 38 and the upper tie plate 46. Several

spacers 54 are arranged in the axial direction of the

fuel rods 47, and hold the gaps between the fuel rods

47 in an appropriate state. The channel box 56 is mounted

on the upper tie plate 46, and surrounds the outer periphery

of the bundle of the fuel rods 47 held by the spacers 54.

The orifice 25 shown in Figs. 14A and 14B is mounted

on the lower tie plate 38 in a manner to be arranged

at the lower end of a space 57 which is defined inside

the lower tie plate and which serves as the channel

of cooling water. The upper end of the space 57 is

the lower surface of a fuel rod support portion 58.

The lower ends of the fuel rods 47 are held by the fuel

rod support portion 58 of the lower tie plate·38.

Fig. 13 shows the detailed structure of the fuel

rod 47. The fuel rod 47 is such that both its ends

are hermetically closed by a lower end plug 49 and an

upper end plug 50, and that a cladding 48 is charged

with a large number of fuel pellets 51. A spring 52

is arranged in a gas plenum within the cladding 48,

and urges the fuel pellets 51.

The aforementioned orifice 25 is a resistance device.

As shown in Figs. 14A and 14B, the orifice 25 is so

constructed that thirteen round bars circular in cross-

section (which may well be circular pipes) 27 are attached

to a ring 26 in a manner to be spaced from one another

and to be parallel to one another. An interspace or

gap 28 to serve as a cooling water passage is formed

between the adjacent round bars 27. Symbol 8A denotes

a throat portion in which the gap 28 is the narrowest.

The gap 28 in the present embodiment has a cross-sectional

area which gradually increases from the throat portion
8A toward an upper stream side and a lower stream side,
and it is defined by a pair of side walls (the side
surfaces of the adjacent round bars 27) which are made
of continuous surfaces having no angled part. The orifice
25 has a plurality of such gaps 28. The round bar 27
is a resistance member. The resistance member has such
a sectional shape that its dimension in a direction
orthogonal to the flow direction of the cooling water
increases continuously toward the lower stream side in
the flow direction (FL) until it reaches the maximum
dimension, whereupon it decreases continuously.

Fig. 15 shows an embodiment of a boiling water
reactor in which fuel assemblies 45 is disposed.

The boiling water reactor 30 has fuel support fixtures
3, a reactor pressure vessel 31, a core lower support
plate 33 and the fuel assemblies 45. A core shroud 32
is arranged in and fixed to the reactor pressure vessel
31. A jet pump 35 is interposed between the reactor
pressure vessel 31 and the core shroud 32. The core
lower support plate 33 is attached to the lower end
part of the core shroud 32 and is arranged inside the
core shroud 32. The plurality of fuel support fixtures
3 are mounted on the core lower support plate 33 while
penetrating this plate 33. The fuel support fixture 3

has a structure shown in Fig. 16, which includes a cruciform
through hole 29 in the central part of a fixture body
21 and four cooling water passageways 22 around the
through hole 29. The inlet opening 23 of each cooling
water passageway 22 lies below the core lower support
plate 33, and is open to a lower plenum 36. The fuel
support fixture is means to support the fuel assembly.

As shown in Fig. 17, the large number of fuel assemblies
45 arranged in the core shroud 32 are supported in such
a manner that a lower tie plate 38 therefor is inserted
in the outlet openings 24 of the cooling water passageways
22 of the fuel support fixtures 3. Fig. 17 is a partial
enlarged view of a portion I in Fig. 15. The upper end
parts of the fuel assemblies 45 are supported by an upper
lattice plate 34 which is disposed in the core shroud
32. That part inside the core shroud 32 in which the
fuel assemblies 45 are arranged is the core. The lower
plenum 36 is formed below the core lower support plate
33 inside the reactor pressure vessel 31. A large number
of control rod guide pipes 39 are disposed within the
lower plenum 36. A control rod driver housing 40 is
joined to the lower end of each control rod guide pipe
39, and it penetrates the reactor pressure vessel 31
to extend below this vessel. Control rods 41 move vertically
within the control rod guide pipes 39, and are put into

and out of the interstices among the fuel assemblies
45 of the core through the through holes 29 of the fuel
support fixtures 3. The control rod 41 is moved by
a control rod driver (not shown) which is disposed in
the control rod driver housing 40.

The boiling water reactor 30 is started up as stated
below. The boiling water reactor 30 which has been
brought into its critical state by drawing the control
rods 41 out of the core is subjected to a temperature-
and pressure-raising operation while the control rods
41 are further extracted. At this time, the core is
supplied with the cooling water. The supply of the
cooling water is performed in such a way that a recirculation
pump (not shown) is driven to spurt the cooling water
from a nozzle into the jet pump 35. The spurted cooling
water absorbs into the jet pump 35, the cooling water
which exists between the reactor pressure vessel 31
and the core shroud 32. The cooling water discharged
from the jet pump 35 flows into the lower plenum 36
and then into the cooling water passageways 22 of the
fuel support fixtures 3, and it is fed into the fuel
assemblies 45 from the outlet openings 24 and through
orifices 25. When passing through the orifice 25, the
cooling water flows through gaps 28.

When the pressure and temperature of the interior

of the reactor pressure vessel 31 have become predetermined

values (about 70 kg/cm^2 and about 280 °C), the control

rods 41 are extracted from the core while the flow rate

of the cooling water to be discharged from the recirculation

pump is held at the flow rate of a 20 % pump operation

state. At this time, the reactor power rises along

a characteristic indicated by a broken line in Fig. 1.

When the reactor power has reached a point D, the extracting

motion of the control rods 41 is stopped. In a case

where the control rods 41 are extracted in a region

in which the reactor power exceeds the point D, fuel

rods in the fuel assemblies 45 might damage due to the

mechanical interaction of claddings versus pellets. In

a case where the reactor power is raised into a state

higher than the point D, the control rods 41 which are

control means for roughly adjusting the reactor power

are held at a stop, and the flow rate of the cooling

water to be fed into the core (the core flow rate) is

increased instead of the motion of the control rods.

The increase of the core flow rate can be achieved by

augmenting the revolution number of the recirculation

pump. The recirculation pump is control means for finely

adjusting the reactor power. Owing to the increase

of the reactor flow rate, the reactor power rises from

the point D to the point C along the straight line BC

shown in Fig. 1. When the reactor power has reached

the point C, the increase of the core flow rate is stopped.

With the consumption of fuel, the reactor power becomes

lower than 100 %. In order to compensate for the lowering

and to hold the reactor power at 100 %, the reactor

flow rate is increased. The compensation of the reactor

power based on the increase of the core flow rate is

limited in relation to the capacity of the recirculation

pump. In a case where the limit has been reached, the

core flow rate is lowered to bring the reactor power

below the point D, and the reactor power is raised to

the point D by the extracting motion of the control

rods 41. Thenceforth, the reactor power is raised to

the point C along the straight line BC as stated before.

With the orifice 25, as in the orifice 5, when

the Reynolds number of the gaps 28 increases, the orifice

coefficient K_{or} decreases as illustrated in Fig. 8.

The critical Reynolds number R_{ec} of the orifice 25 (the

transition starting point of the orifice coefficient

K_{or}) is 40×10^4. The gaps 28 of the orifice 25 are

formed with laminar boundary layers as shown in Fig. 9,

in a region of $R_e < 40 \times 10^4$, and with turbulent boundary

layers as shown in Fig. 10, in a region of $R_e > 40 \times 10^4$.

The diameter D of the round bars 27 of the orifice 25

is 0.735 cm, and the number of the round bars 27 is

seven. The total projection area A_{Ob} of the round bars
27 attached to a ring 26 is 89.3 cm^2, the total projection
area A_F of the gaps 28 formed between the round bars
27 is 13.2 cm^2, and the area of the inner side of the
ring 26 is 102.5 (= A_{Ob} + A_F). The inside diameter
of the ring 26 is 6.6 cm.

In the boiling water reactor 30, when the Reynolds
number R_e exceeds the critical Reynolds number R_{ec} owing
to the increase of the core flow rate, the pressure
loss of the orifice 25 begins to decrease. The pressure
loss at the point fo time at which the reactor power
is 100 % (the point C in Fig. 1) decreases by about
22 % as compared with the pressure loss at the point
of time corresponding to the point D. In the present
embodiment, therefore, the cooling water flow rate which
is discharged from the recirculation pump at the point
C in Fig. 1 becomes less by the decrement of the pressure
loss of the orifice 25 than the cooling water flow rate
which is discharged from the recirculation pump at the
point C in Fig. 1 in the prior-art boiling water reactor
employing the fuel support fixtures 3 and the prior-art
fuel assemblies (fuel assemblies 37 to be described
later). The capacity of the recirculation pump in the
present embodiment is equal to the capacity thereof
in the prior-art boiling water reactor. With the present

embodiment, accordingly, the increment of the core flow
rate after the establishment of the state of the point
C in Fig. 1 becomes larger than in the prior art. That
is, in the present embodiment, the core flow rate can
be made more than in the prior art as indicated by a
broken line L_1 in Fig. 5C. With the present embodiment,
therefore, the proportion at which the compensation
of the reactor power lowering attributed to the fuel
consumption can be performed by the increase of the
core flow rate, that is, the control range of the reactor
power by the core flow rate as utilizes the control means
for finely adjusting the reactor power can be increased
or expanded more than in the prior art. This leads
to a remarkable decrease in the number of times by which
the extraction motion of the control rods 41 is executed
after bringing the reactor power below the point D, and
the utilization factor of the nuclear reactor in the
present embodiment can be rendered much higher than
that of the prior art.

If the recirculation pump trips during the operation
with the reactor power of 100 %, the core flow rate
decreases and the cooling water in the core falls into
the natural circulation state. With the decrease of
the core flow rate, the reactor power lowers along the
straight line BC in Fig. 1 and down to the power of the

point B.   When the core flow rate becomes the flow rate

of the natural circulation state in this manner, the

flow state in the gaps 28 of the orifice 25 becomes

as shown in Fig. 9, and the orifice coefficient K_{or}

of the orifice 25 increases.   Accordingly, the present

embodiment can prevent the phenomenon in which the core

flow rate becomes unstable under the natural circulation

state.

In this way, using the orifice 25 which has quite

no movable part, the present embodiment can achieve

the prevention of the instability for low flow rates

and the enhancement of the utilization factor of the

nuclear reactor.

Since, in the present embodiment, the plurality

of round bars 27 are arranged in parallel, the burble

condition of the boundary layer is determined by the

velocity of flow of the cooling water flowing through

the gap 28 and is not affected by any condition on the

upper stream side with respect to the orifice 25, namely,

within the lower plenum 36.   Besides, since in the present

embodiment the plurality of gaps 28 are formed by arranging

the plurality of round bars 27 in the inlet openings

23 of the cooling water passageways 22 of the fuel support

fixture 20, the flow direction of the cooling water

which enters the gaps 28 from the lower plenum 36 is

forcibly set right, and the appearance of vortices in the cooling water passageways 22 lessens. This is also one factor for the prevention of the instability of the flow. In particular, the cooling water in the lower plenum 36 gets to the fuel support fixtures 20 through the interstices among the large number of control rod guide pipes 39 erected within the lower plenum 36, so that the flow is drastically disturbed by the control rod guide pipes 39 in the course. Accordingly, the cooling water flows into the cooling water circulation holes 22 of the fuel support fixtures 20 in all directions. Since the orifice 25 is formed with the plurality of gaps 28 by the plurality of round bars 27, it has a very great function of reforming the drastically disturbed streams of the cooling water into the flow of the specified direction within the cooling water circulation holes 22.

In the embodiment thus far described, the orifice 25 is disposed in the lower tie plate 38 of the fuel assembly. Even when the orifice 25 is not mounted on the fuel assembly but is mounted on the fuel support fixture which is a fuel assembly supporting device, the same effects as those of the embodiment shown in Fig. 15 can be attained. Such an embodiment will be described below.

Fig. 18 shows the vicinity of the fuel support

fixture of the boiling water reactor of the present

embodiment, and illustrates a part corresponding to

the portion I in Fig. 15. In the boiling water reactor

of the present embodiment, the construction of parts

not shown in Fig. 18 is the same as in Fig. 15. That

is, the present embodiment differs from the embodiment

of Fig. 15 in that the orifice 25 is mounted on the

inlet opening 23 of the cooling water passageway 22

of the fuel support fixture 20, not on the fuel assembly.

As shown in Figs. 18 and 19, the fuel support fixture

20 has a fixture body 21 internally provided with four

cooling water passageways 22 and the orifices 25 fitted

in the inlet openings 23 of the cooling water passageways

22. Likewise to the fuel support fixture 3, the fuel

support fixture 20 is mounted on the core lower support

plate 33. The orifice 25 lies below the core lower

support plate 33, and is open to the lower plenum 36.

The fuel assembly 37 is held by the fuel support fixture

3 in such a way that the lower end of the lower tie

plate 38 is inserted into the outlet opening 24 of the

cooling water passageway 22. The fuel assembly 37 is

the fuel assembly 45 from which the orifice 25 has been

removed.

During the operation of the boiling water rezctor

of the present embodiment, the cooling water in the

lower plenum 36 flows from the inlet openings 23 into
the cooling water passageways 22 of each fuel support
fixture 20 through the orifices 25 and is supplied into
the fuel assemblies 45. The orifice 25 functions similarly
to that mounted on the fuel assembly 45 as in the preceding
embodiment. That is, the orifice 25 forms laminar boundary
layers and turbulent boundary layers as shown in Figs. 9
and 10 and changes the pressure loss in accordance with
the variation of the core flow rate.

With the present embodiment, effects similar to
those of the preceding embodiment are attained. The
cooling water the streams of which are drastically
disturbed by the control rod guide pipes 39 as stated
before flows directly into each orifice 25 mounted on
the fuel support fixture 20, in all directions. Since
the orifice 25 is formed with the plurality of gaps
28 by the plurality of round bars 27, it has a very
great function of reforming the cooling water streams
entering it in all the directions, into the flow of
a specified direction.

The orifice 25 is not restricted to the position
shown in Fig. 12 or Fig. 18, but may be disposed at any
position in the lower tie plate of the fuel assembly
and the cooling water passageway 22 of the fuel support
fixture. In other words, in the state in which the fuel

assemblies are mounted on the fuel support fixtures

in the boiling water reactor, the orifice 23 can be

disposed in any desired place (of either the fuel assembly

or the fuel support fixture) within the channel of the

cooling water extending from the inlet of the cooling

water passageway 22 of the fuel support fixture to the

lower surface of the fuel rod supporting portion 58 of

the lower tie plate 38. In this regard, however, the

attachment of the orifice 25 to the fuel assembly is

easier of application to an existing reactor plant than

the attachment thereof to the fuel support fixture. This

is because the replacement of the fuel assemblies in

the nuclear reactor is facilitated.

In the embodiment of the boiling water reactor

in Fig. 18, various structures of the orifice 25 satisfying

predetermined conditions of the boiling water reactor

were studied. As examples of the specifications of

the orifice 25 meeting the predetermined conditions

of the boiling water reactor, ones listed in Table 1

have been obtained. They correspond to an instance

in which the ring 26 of the orifice 25 has an inside

diameter of 6.2 cm. The channel area of the fuel assembly

is the cross-sectional area of a cooling water channel

in the channel box 37 which overlies the lower tie plate

38 and in which the fuel rods 47 exist. In addition,

the cooling water flow rate at which the pressure loss

coefficient lowers is the cooling water flow rate of

a point R_0 in Fig. 8.

TABLE 1

No.	Diameter (mm) of Round Bar 27	Number of Bars	Pitch (mm) of Round Bars 27	Channel Area (cm^2) of Fuel Assembly	Pressure Loss Coefficient	Cooling Water Flow Rate (kg/sec) at which Pressure Loss Coefficient Lowers
1	5.13	7	9.54	96	28	9.5
2	3.85	9	7.14	96	28	13.0
3	5.32	6	10.28	101	28	9.5
4	3.99	8	7.62	101	28	13.0
5	4.14	10	6.53	96	50	9.5
6	3.10	13	4.90	96	50	13.0
7	4.30	9	7.05	101	50	9.5
8	3.23	12	5.25	101	50	13.0

Other embodiments of the orifice 25 will be described below.

An orifice 25A shown in Figs. 20A and 20B is such that as resistors, bars of elliptic section 27A are employed instead of the round bars 27, and that they are arrayed in parallel in a number of three. The bar 27A has the major axis of the ellipse arranged perpendicularly to the direction of arrow FL (the direction of flow). This arrangement corresponds to Fig. 11A. In addition, the ratio of the major and minor axes of the ellipse is 2, and the diameter of the ellipse is 2.8 cm. This orifice 25A can demonstrate the same function as that of the orifice 25, and it is applicable to a case where the transition is to be caused at a high flow rate (R_{ec} = 1.6 x 10^6). Moreover, since the number of the bars 27A is small, the fabrication of the orifice 25A is simple. It is also possible to use the orifice with the bars 27A arranged so that the major axis of the ellipse may become parallel to the flow. As a feature in this case, the pressure loss of the orifice decreases gently in the vicinity of the critical Reynolds number. Further, an orifice in which resistors 27B as shown in Fig. 21 are attached to the ring 26 exhibits a pressure loss which decreases gently similarly. The resistor 27B is arranged with its part F facing the upper stream

side of the flow.

An orifice 25C shown in Figs. 22A and 22B is so constructed that a bar 27C of a triangular section having smooth corner parts is employed as a resistor, and that the bars 27C are mounted on a ring 26. The orifice 25C is so oriented that one of the vertices of the section of the bar 27C lies downstream as illustrated in Fig. 11F. Both the base length and the height of the section of the bar 27C are 15 cm. Each corner part of the section of the bar 27C is rounded with a curvature whose radius is approximately a quarter of the base length. The orifice 25C has the bars 27C arrayed in parallel in a number of eight. The critical Reynolds number of the orifice 25C becomes about 6×10^5. The present embodiment has the advantage that the transition condition can be varied by changing the curvature of the corner parts. The orifice 25C has the same function as that of the orifice 25.

An orifice 25D shown in Figs. 23A and 23B has the same constituents as those of the orifice 25. In the orifice 25D, however, the gaps 28 between the round bars 27 are wider in central parts and narrower on both the sides and are not uniform, as shown in Fig. 23B. Owing to the non-uniform gaps 28 between the round bars 27, a distribution of the Reynolds number arises in

a direction orthogonal to the flow direction of the orifice 25D, and the pressure loss lowers gently. A nuclear reactor employing the orifices 25D is capable of a stabler operation. Also the orifice 25D has the same function as that of the orifice 25.

An orifice 25E shown in Figs. 24A and 24B has the same constituents as those of the orifice 25. The orifice 25E has the gaps of the round bars 27 narrowed on one side and widened on the other side, thereby to establish a distribution of the velocity of flow.

Likewise to the orifice 25, each of the orifices 25A - 25E can be mounted on any place in the fuel assembly and the fuel support fixture. In that case, the function of each orifice does not differ from that of the orifice 25 at all. The resistors disposed in each orifice may well be attached directly to the lower tie plate 38 of the fuel assembly 45 or the fixture body 21 of the fuel support fixture 20 in the cooling water passageway 22 without interposing the ring 26.

As regards the orifices 25A and 25C, the fabrication of the bars being the resistors is troublesome. As the resistors, the round bars are the easiest of fabrication and are readily available. Therefore, the orifices employing the round bars (or circular pipes) as the resistors can be fabricated most easily.

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According to the present invention, the instability of a nuclear reactor under the state of a low coolant flow rate can be prevented using resistors which have no movable part.

What is claimed is:

1. In a fuel assembly for a nuclear reactor having
an upper tie plate, a lower tie plate, and a plurality
of fuel rods each of which has both its ends retained
by the upper tie plate and the lower tie plate; a fuel
assembly for a nuclear reactor characterized in that
a resistance device (25) is disposed in said lower tie
plate (38), said resistance device (25) having a plurality
of coolant passages (28) formed with throat portions
(8A), a cross-sectional area of said each coolant passage
(28) increasing continuously from said throat portion
(8A) toward an upper stream side and a lower stream
side respectively, each of opposing side walls of said
each coolant passage (28) being constructed of a continuous
surface having no angled part from the upper stream
side of said throat portion (8A) to the lower stream
side thereof.

2. A fuel assembly for a nuclear reactor according
to Claim 1, wherein said resistance device (25) includes
a plurality of resistance members (27), said each coolant
passage (25) is formed between the adjacent resistance
members (27), and each of the opposing side walls of
said each coolant passage (25) is a surface of said
resistance member (27).

3. A fuel assembly for a nuclear reactor according
to Claim 2, wherein said resistance member (27) disposed

in said resistance device (25) is a round bar.

4. In a nuclear reactor having a reactor vessel, a core support member which is disposed in the reactor vessel, a plurality of fuel assembly supporters which are mounted on the core support member and which have first coolant passageways therein, and a plurality of reactor fuel assemblies which are supported by said fuel assembly supporters and each of which includes a lower tie plate having a second coolant passageway therein, an upper tie plate, and a plurality of fuel rods each having both its ends retained by the lower tie plate and the upper tie plate; a nuclear reactor characterized in that a resistance device (25) is disposed in either of said first coolant passageway (22) and said second coolant passageway (57), said resistance device (25) having a plurality of coolant passages (28) formed with throat portions (8A), a cross-sectional area of said each coolant passage (28) increasing continuously from said throat portion (8A) toward an upper stream side and a lower stream side respectively, each of opposing side walls of said each coolant passage (28) being constructed of a continuous surface having no angled part from the upper stream side of said throat portion (8A) to the lower stream side thereof.

5. A nuclear reactor according to Claim 4, wherein

said resistance device (25) includes a plurality of resistance members (27), said each coolant passage (28) is formed between the adjacent resistance members (27), and each of the opposing side walls of said each coolant passage (28) is a surface of said resistance member (27).

6. A nuclear reactor according to Claim 5, wherein said resistance member (27) disposed in said resistance device (25) is a round bar.